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Exercising multidisciplinary approach to assess interrelationship between energy use, carbon emission and land use change in a metropolitan city of Pakistan

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ABSTRACT

Population of two cities in Pakistan has already crossed the 10-million figure and for the rest of the areas in the country populations are also increasing rapidly. Urbanization has boosted the use of energy in the cities and so is greenhouse gas (GHG) emissions but the ground situation as to the extent, vulnerability, past trends and future scenarios are not unveiled for the cities of Pakistan. Dearth of data in Pakistan is a huge hindrance to the investigation of energy use and actual GHG emissions. We dared to take steps in addressing this case and put preliminary efforts in compiling baseline sectoral breakdown of energy use, carbon emission and land cover/land use. Furthermore, the relationship of CO_2 source and sink is also explored. This study mainly tries to achieve three objectives. The results illustrate that industrial and residential sectors are vibrant consumers of energy and CO_2 emitters among all other sectors of the city. Sparse trees in the city and reduced agriculture areas by more than one-half in 2009 compared with those in 1975 are the main reasons for increased energy use and reduced CO_2 emissions from agriculture sector as well. However, all the other sectors have increased their CO_2 emissions in an escalating trend. The forecast analysis portrays the same trend too. Therefore, there is a need to make policy makers recognize such vulnerable situation of energy use and GHG emissions for them to take proper and timely actions to cope with the threats of climate change which can occur anytime in the very near future.

Contents

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1. Introduction

Inhabitants of big cities are considered as major drivers of global greenhouse gases emission as global urban population is now surpassing the 50% line [1]. Reducing greenhouse gas emissions as CO_2 source and increasing CO_2 sink are referred to as climate change mitigation measures [2]. Every single country is naturally concerned with the potential damages that could be instigated from the impacts of climate change in the coming decades especially on its terrain as well as globally since such impacts could affect local and international policies, regional planning, resource use, trading patterns, and the prosperity of its people [3]. Pakistan is listed by World Bank in the top 12 countries vulnerable to climate threats as shown in Table 1. In Pakistan, energy use per capita has increased from 272 kg in 1971 to 499 kg in 2008 and the GDP shoot up from \$10,602 million to \$161,898 million during the same period [4]. In contrast, forest areas had shrunk from 25,270 square kilometers (km^2) to 16,870 km^2. Pakistan had agreed to increase its forest cover from the current 4% to 7% by 2015 under the Millennium Development Goals (MDGs), but the situation seems to be getting worse day by day and the forest cover had not increased even at 1% after the fleeting 10 years in spite of the agreement [5].

The total primary energy supply mix of Pakistan consists of fossil fuels which is approximately 60% of the supply. A reasonable share of biomass based energy (e.g. wood fuel, agricultural and animal waste also called animal dung) is also present in the energy supply of Pakistan [6] although these are used mainly in rural areas and are less popular in urban territories. Recent energy use statistics of 2010 depicted a total share of petroleum products in agriculture, commercial, industrial, residential and transport sectors of Pakistan at 94.70, 7309.80, 2666.90, 297.80 and 8999.70 kilotonnes, respectively. A sectoral breakdown of the energy consumption share in Pakistan revealed that transport sector is the largest consumer of petroleum products followed by the commercial and industrial sectors. Similarly, the industrial sector is also a major consumer of gas with a total share of 65% followed by residential sector at 23% and transport sector with a share of 8% in 2010, while gas and coal are not consumed in the country's agriculture sector. Residential sector is the largest consumer of electricity accounting for 49% of the country's total consumption, industrial sector ranked second at 34% followed by agriculture and commercial sectors at 10% and 7% of the total electricity consumption, respectively [7].

In 2008, greenhouse gases (GHGs) emission of Pakistan which was equivalent to 309 million tonnes (mt) of CO_2, comprised mainly carbon dioxide gas accounting for 54%, methane 36%, nitrous oxide 9% and other gases at 1% [8]. CO_2 emission of Pakistan increased from 61.40 mt of CO_2 equivalent to 138.42 mt of CO_2 equivalent between 2000 and 2009 [9]. The CO_2 emitted in Pakistan had been chiefly contributed by the transport and industrial sectors. The data also portrays the fact that CO_2 sources are increasing more rapidly than the sinks (vegetation) which are not increasing as rapidly as the sources.

A substantial concern of the current era's research is integration of different disciplines, tools, models and/or techniques to deal with similar situation, considering that multidisciplinary approaches are currently being appreciated in the researchers' community. Noteworthy researches were conducted in this field by [10–14] as they integrated the different approaches, techniques, and tools, and explained that integration could be more dynamic especially in environment cum economic studies.

Most of the preceding studies have focused on energy use, carbon emission and mitigation strategies to deliver the baseline for advance studies conducted afterwards. Dynamic edge was provided by developed countries starting with carbon footprints of countries, territories and cities. Among those studies, [15–21] explored the insight into the direction of carbon emission, footprint and energy use among others, at altered levels. In addition, further studies were grounded on GHGs mitigation assessments and accordingly policy provisions at different scales of economies (see for example [22–26]), many of which have provided policy implications vis-à-vis carbon and climate change mitigations based on the valued information and results.

Within the Asian region, [13,27–37] have conducted various studies related to energy use and carbon emission inventories, policy implications and GHG emission reduction. Furthermore, various models/tools and techniques were utilized to fulfill their objectives. There have also been focus on biogas from agricultural waste, electricity emissions, and renewable energy and this interesting contribution has been accomplished by [38,39].

Specifically in Pakistan, such studies are not available or are only very limited, and most of such studies focused on national level, sole sector and/or issue rather than on city and/or sectors. For instance, [40–42] analyzed the energy security of Pakistan at national level along with the potentials of renewable energy resources and the possible barriers in exploring the resources. In addition, [43] conducted a preliminary study which discussed urbanization, fossil fuel consumption and CO_2 emission in the largest metropolitan city (Karachi) in Pakistan but did not describe comprehensively the energy use trend, the factors affecting emissions and/or energy use, and above all, the land use change. As a result, there is no use of having scientific model and tools to analyze the situation and interpret the results. Afterwards, [44,45] conducted studies on monitoring and evaluation of urban transportation and air pollution of different cities, the first of which were Islamabad and Rawalpindi, followed by the next choice which is Karachi, and used different tools to achieve the set targets while focusing exclusively on the transportation sector. Furthermore, [6] mentioned the sustainable energy resources options of Pakistan and described the overall present and future scenario, while [46] addressed the requirements of the textile industry particularly in the context of solar water heating and suggested possible policy measures at the country level. In a related development, [47,48] explained the hydropower and biomass energy uses in the country and presented past and future contexts to reveal the reality to policy makers. Hence, none of the previous studies so far focused on major sectors of the economy of metropolitan/mega cities and also did not integrate energy use, carbon emission and land use change in the particular context of cities and urban areas of Pakistan.

The above studies indicated that the description of Pakistan's energy supply breakdown in terms of consumption and GHGs emission is indeed available, although in the form of collective and mix information of urban and rural regions of Pakistan, without taking into account the fact that the situation could vary from city to city and province to province. Ground realities and/or entire situation of energy use and GHGs emission are not available for the mega cities and/or even for metropolitan cities of Pakistan. There are no concrete database and inventories available as of now from where one can figure out the situation of the heavily populated urban areas which are considered the hubs of commercialization and industrialization. In addition to inventories, exhaustive information on energy use, GHG emission and land use change analysis are prerequisites in this period especially in dealing with the impacts of climate change in the future, which can cause any harm anytime in any parts of the world [49]. Pakistan signed the Kyoto Protocol but since the country is not considered a promising economy of Asia as it is categorized as least developing country in the region, therefore the stress to adapt to and mitigate the impacts of climate change does not exist. However, sooner or later this issue should be addressed which would call for pre-emptive action in order to stimulate elements which can be helpful in coping with such circumstances. Therefore, in order to cope with future climate change related challenges, it is necessary to investigate the ground

Table 1
Six climate threats to countries of the world [50].

Drought	Flood	Storm	Coastal 1 m	Agriculture
Malawi	Bangladesh	Philippines	All low-lying Island states	Sudan
Ethiopia	China	Bangladesh	Vietnam	Senegal
Zimbabwe	India	Madagascar	Egypt	Zimbabwe
India	Cambodia	Vietnam	Tunisia	Mali
Mozambique	Mozambique	Moldova	Indonesia	Zambia
Niger	Laos	Mongolia	Mauritania	Morocco
Mauritania	Pakistan	Haiti	China	Niger
Eritrea	Sri Lanka	Samoa	Mexico	India
Sudan	Thailand	Tonga	Myanmar	Malawi
Chad	Vietnam	China	Bangladesh	Algeria
Kenya	Benin	Honduras	Senegal	Ethiopia
Iran	Rwanda	Fiji	Libya	Pakistan

realities, strengths, weaknesses and appropriate measures so that plans of action could be formulated especially for exceedingly urbanized and mega cities.

Accordingly, the result of a preliminary study on energy use, carbon emission and land use change of a metropolitan area using multiple approaches (economic, environment and remote sensing) and tools is presented in this paper. A distinctive feature of this study is the relationship that was developed between energy use, carbon emission, land use change of five major sectors of the economy, namely: agricultural, commercial, industrial, residential, and transportation. Moreover, the past, current and future situations of energy use and carbon emissions of a city are also described with the help of variety of tools, models, techniques, and consequently, policy implications are provided. We also tried to explain the relationship of GHG sources and sinks in the city using different models, because the assemblage of these methods would expose the realism. To the best of our knowledge, there are exceptionally rare studies in developing countries at city level which combine energy use, carbon emission and land use change using multiple disciplines, and none in Pakistan. Therefore, this paper aims to accomplish three objectives. First is the compilation of baseline information of sectoral energy use of five major sectors, their historical trends, current situation and forecasting; next is the estimation of carbon emission from energy use of five sectors, historical trends current situation and forecasting; and last is the assessment of land use change of the city in order to verify the statement that CO_2 sources in the area have increased more than the sinks.

This paper is organized into four main sections. Section 1 which includes the introduction is followed by Section 2 which explains the methodology, the study area, and data collection, and methods/tools used. Section 3 illustrates the results and discussion in details, while the conclusion is contained by Section 4.

2. Data and methods

2.1. Study area

Lahore Metropolitan Area (LMA) is selected as the study area for this research. LMA is the capital city of Punjab Province (largest province of Pakistan in terms of population and GDP). The hub of commercialization and industrialization, it is also famed as the "Heart of Pakistan", which is more than 1000 years old and situated on the left bank of Ravi River. The city lies from 31°15′ to 31°42′ north latitude and 74°01′ to 74°39′ east longitude. The general altitude of the area is 208–213 m above mean sea level. The climate of the city impinges upon two extremes: the mean maximum and minimum temperatures during summer vary between 40.4 °C and 27.4 °C while during winter it could vary between 22.0 °C and 5.9 °C, respectively. The population of LMA is now almost 10.1 million from 1.6 million in 1961 to 6.6 million in 1999 [51]. According to the Economic Survey of Pakistan 2010, the GDP (PPP) of LMA in 2009 was $42 billion and this is expected to grow to $102 billion in 2025 at a growth rate of 5.6% which is higher than the growth rate of the largest metropolitan city, Karachi in Pakistan. LMA is further divided into 9 towns, namely: Data Ganj Buksh, Ravi, Allama Iqbal, Nishtar, Shalimar, Wagha, Gulberg, Samanadbad, and Aziz Bhatti. Since 1961 to date, its urbanization rate is higher than 80%, likewise rural–urban migration rate is almost 24.7%. Major activities in city are particularly related to services and industry [51].

2.2. Data used

Data for this study was collected from primary and secondary sources that comprised the 40-year energy consumption data from 1971 to 2010 of the five sectors, specifically agriculture, commercial, industry, residential, and transport. Secondary data included among others, topographical maps, meteorological data, profile studies, landsat satellite scenes, and land use distributions. Collection of primary data was done in response to the requirements of remote sensing tools, technically called ground truth in the form of field survey in order to confirm the locations of different places in the study area. The factors considered for the source of the satellite data were: (1) availability of long time series of imagery for the study area, and (2) less than 20% of cloud cover, witnessed in the months of September, October, November and December which are the post monsoon months. With these two criteria, four landsat scenes of LMA between 1975 and 2009 were acquired. The first image Landsat Multi Spectral Scanner (MSS) data was obtained in 1975, the other landsat MSS data from 1981, Landsat Enhanced Thematic Mapper (ETM) data from 1999, and Landsat ETM in 2009. Since landsat data that fulfills the requirements of the study for 1981–1998 was not available, a sub-area of 193,204 ha was extracted from the imagery. The details of the imagery are presented in Table 2.

The other data used in the study for reference and analysis include detailed topographic maps at scale 1:5000 acquired from Survey of Pakistan, ground reference data obtained from the land survey using hand held Geographical Positioning System (GPS), and reference data collected corresponding to five main land cover/land use now and onwards (LC/LU) classes. A brief description of the classes is given in Table 3.

Table 2
Landsat data specifications.

Date	Imagery type	Path/row	Nominal spatial resolution (m)
29.11.1975	Landsat-MSS	160-038 (WRS-1)	60
15.06.1981	Landsat-MSS	160-038 (WRS-1)	60
11.04.1999	Landsat-TM	149-038 (WRS-2)	30
17.12.2009	Landsat-TM	149-038 (WRS-2)	30

Table 3
Land use classification in Lahore Metropolitan Area.

No.	Classes	Definitions
1	Built-up areas	Area covered by concrete or asphalt which covered all built up areas and major roads with supporting infrastructures
2	Bare areas	Area of sparse vegetation, which also includes the cultivated land without crops and barren rocks
3	Water	All areas of open water
4	Dense vegetation/agriculture fields	Well bloomed agricultural crops
5	Sparse vegetation/agriculture fields	Immature seasonal crops, may be mixed with sparse vegetation in fallow fields
6	Grasses	Dense vegetation around the residential areas that include grasslands on inbuilt residential areas
7	Sparse trees	Sparse vegetation around residential areas that include tress or gardens with trees

2.3. Methodological approach

In order to achieve the objectives of this study, we adopted an integrated and multi-disciplinary approach. For this purpose, the agriculture, commercial, industry, residential and transport sectors were selected. In addition, four major energy sources abundantly used in LMA such as petroleum products, gas, coal (direct sources), and electricity (indirect source) were considered. Energy demand in this study is assumed as the energy consumed in the city since a sectoral breakdown of energy is not available in statistical data sources for any city of Pakistan, and is also assumed as all energy consumed within the city boundary. In the estimation, we selected only carbon dioxide (CO_2) gas among the GHGs being the major gas emitted in the country. The sources of data include the Ministry of Petroleum and Natural Resources of Pakistan, Statistical Bureau of Pakistan, and Hydrocarbon Development Institute of Pakistan. The emission factors of GHG for electricity consumption were collected from Lahore Electricity Supply Company (LESCO) 2010.

The foremost objective of the study is to compile baseline information on sectoral energy use of the city, their historical trends, current situation and forecasts. Thus, the energy consumption data of 40 years from 1971 to 2010 is compiled as this explains the past trends and based on this historical data, we were able to forecast the energy consumption of the city for the next 20 years. For the forecast, ARIMA model was selected since it is the most popular econometric model variably used for this purpose. The autoregressive integrated moving average (ARIMA), is the most famous model in time series forecasting analysis [52–56]. The origin of ARIMA model is the autoregressive model (AR), the moving average model (MA) and the combination of the AR and MA, combining into the ARMA model, which were introduced in 1926, 1937 and 1938, respectively [53,57,58]. ARIMA model is a combination of AR coefficients, which are multiplied by past values of the time series data and other MA coefficients, and multiplied by past random shocks [57]. An identified underlying process is generated based on observations into a time series for generating a good model that precisely shows the process generating mechanism [57]. An important point to note is on the use of the ARIMA model, which requires either a stationary time series or a time series that is stationary after one or more differencing [59]. Thus, we used the OLS technique, unit root and Dickey–Fuller (DF) methods and ARIMA model, which are all econometric based models and/or techniques. The functional form of this model is as follows:

$$\begin{aligned}\Delta dYt &= \delta + \phi 1\, \Delta dYt - 1 + \phi 2\, \Delta dYt - 2 + \cdots + \phi p\, \Delta dYt\text{-}p + \varepsilon_t \\ &\quad - \theta 1 \varepsilon_t - 1 - \theta 2 \varepsilon t - 2 - \cdots - \theta q \varepsilon t - q\, OR(1 - \theta 1B - \phi 1B2 \\ &\quad - \cdots - \phi 1Bp)(1 - B)dYt = \delta + (1 - \phi 1B - \phi 1B2 \\ &\quad - \cdots - \phi qBp)\varepsilon t \end{aligned} \tag{1}$$

where Yt is the observation at time t, $Yt\text{-}p$ is observation at time $t\text{-}p$, δ is the constant term, $\phi 1$, ϕp is MA parameter, εt is the white noise process or error at time t, $\varepsilon t\text{-}q$ is the white noise process or error at time $t\text{-}q$, Δd is dth order differences (difference order d) and B is the backward shift operation (defined as $BkXt = Xt - k$). Further, we use MS Excel, E-views 3.0 and the Statgraphics plus software to simulate the model and generate the forecasting results.

The second objective is to estimate carbon emission from the energy use of five major sectors, historical trends current situation and forecasts. In order to achieve this goal, we used the same sectors, the same four energy sources and the same assumptions which we used to calculate the energy consumption and we applied Eq. (2) to estimate the carbon dioxide from direct energy sources:

$$CO_{2\,direct\ energy} = \sum i\, C_{combusted\ fuel\ type\ i} \times I_{combusted\ fuel\ type} \tag{2}$$

where $CO_{2\,direct\ energy}$ is annual CO_2 emission from combustion of fuels for non-electricity energy, $C_{combusted\ fuel\ type\ i}$ is annual consumption of fuel type i and $I_{combusted\ fuel\ type}$ is CO_2 emission factor of combusted fuel type i. Emission factors for each fuel type are taken from the default emission factors (tier 1) of the 2006 IPCC guidelines for National Greenhouse Gas Inventories [60].

We calculate CO_2 emission from indirect energy source (electricity) by following formula:

$$CO_{2\,indirect\ energy} = C_{electricity} \times LF \times I_{electricity} \tag{3}$$

where $CO_{2\,indirect\ energy}$ is annual CO_2 emission from electricity consumption, $C_{electricity}$ is annual electricity consumption, LF line loss factor and $I_{electricity}$ is CO_2 emission factor. Since [17] proposed that GHG emission from electricity consumption can be calculated by using Eq. (3), therefore this is a valid method to calculate the emissions from electricity consumption.

Third goal is the assessment of land use change of the city in order to verify the statement that CO_2 sources in the area have increased more than the sinks. In performing the assessment of LC/LU change, the most commonly used modern method of post classification comparison change detection was applied. The procedure consists of the following steps: (1) pre-processing, (2) formulation of classification schemes, (3) supervised image classification, and (4) change detection.

2.3.1. Pre-processing

The purpose of pre-processing is to perform a geometric rectification which is critical for producing spatially correct temporal maps that show the LC/LU. Geometric correction was performed using topographic maps at scale of 1:5000, where the controlled points were generated using GPS. Table 4 demonstrates the number of control points used and the obtained root-mean-square error (RMSE). The image for 2009 was geometrically corrected using 22 ground control points (GCPs). The images for 1999, 1981 and 1975 are geometrically corrected using image to image rectification with reference to the 2009 imagery.

Table 4
Landsat imagery specifications.

Image date	No. of control points	RMSE (pixels)
29.11.1975	29	1.02
15.06.1981	31	0.98
11.04.1999	36	0.71
17.12.2009	41	0.76

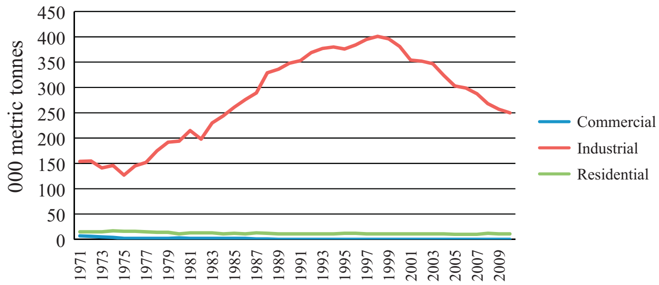

Fig. 1. Coal consumption. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

2.3.2. Formulation of classification

Table 3 shows the land use classification scheme developed for the study area. The inputs for the classification were mainly based on prior knowledge of the study area.

2.3.3. Supervised image classification

According to [61], the most obvious method for LU change detection is the comparative analysis of spectral classification for times $t1$ and $t2$ produced independently. It should be noted however, that accuracy of the change map will be the product of accuracy for each individual classification. Keeping this in view, the Landsat data for four dates are classified independently using the supervised classification with maximum likelihood algorithm. Further smoothing was performed on the classified images with a 3×3 kernel majority filter to reduce the number of wrongly classified pixels.

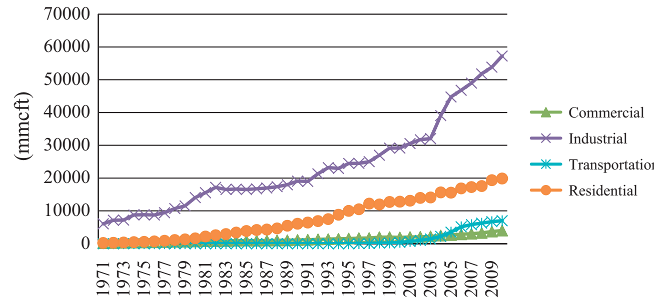

Fig. 2. Gas consumption. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

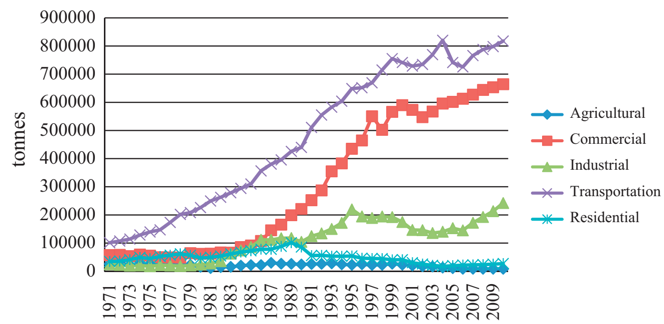

Fig. 3. Consumption of petroleum products. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

3. Results and discussion

3.1. Energy consumption of LMA

Fig. 1 explains the coal consumption trend of LMA from 1971 to 2010 for three[1] sectors. It is evident from the figure that industrial sector has been dominant since 1971 to date and the sector's consumption of coal increased gradually starting from 1971. While coal consumption in commercial sector had stopped since 1989 but before such time the share of the commercial sector in terms of total coal consumption was 4% only in 1971 while the total share of the residential sector was 9%. In 1971, coal consumption in the industrial sector was 154 thousand metric tonnes which increased to 250 thousand metric tonnes in 2010. Although to a large extent the percentage increase is not very significant because coal is already a non-eminent energy source for cities in Pakistan but it is still being utilized in industrial sector with increasing trend. Currently in the LMA, the total share is 96%, 4% and 0% in industrial, residential and commercial sectors, respectively.

For gas consumption, four sectors were considered but agriculture sector was omitted while the transportation sector was included. It is worth mentioning that gas consumption in the transportation sector started from 1991 (Fig. 2). The shares of commercial, industrial, residential and transportation sectors in total gas consumption were 3%, 94%, 3% and 0%, respectively in 1971 while industry has always been dominant in terms of gas consumption although its share decreased currently to 65% but still industry is ranked as the major sector among all sectors in gas consumption. In the industrial sector, gas consumption has reached almost 10 times greater than its consumption in 1971, likewise for the residential sector where gas consumption increased 96 times more than in 1971. The transportation sector is the emerging consumer of gas in LMA. From 1991 to date its gas consumption has been increasing with escalating trend and drastically growing. The share of the transportation sector is currently 8% of the total share of gas consumption of the selected major sectors. Hence, the industrial sector is currently the dominant consumer of gas energy in the city.

Petroleum products are the most popular source of energy in Pakistan as well as in LMA, and this is the only energy source being used by all sectors. Fig. 3 demonstrates the petroleum consumption in the city. Transportation sector has always been the leading consumer in this category followed by the commercial and industrial sectors. In 1971, the total shares of the agricultural, commercial, industrial, residential, and transportation sectors were 11%, 23%, 10%, 14%, and 42%, respectively. However, such shares had been altered to 0%, 38%, 14%, 2%, and 46%, respectively in 2010. Although the share of agriculture in petroleum consumption was 0% in 2010, still this energy source is used in the agricultural sector but the share is negligible compared with those of the other sectors of the economy. Therefore, consumption of petroleum products is increasing rapidly in transportation and commercial sectors while increasing with escalating trend in the industrial sector but with slower pace than the transportation and commercial sectors.

Electricity is consumed by four[2] sectors of the city of which the residential and industrial sectors are dominant with consumption of 3887.36 and 2718.78 Giga watt hour (GWh), respectively in 2010 (Fig. 4). Similarly, the agriculture and commercial sectors are also adequate consumers of electricity accounting for 10% and 7%, respectively of the total share. In 1971, the total shares of the agricultural, commercial, industrial and residential sectors were 20%, 8%, 59%, and 13%, respectively. Later, the industrial and residential sectors appeared as competitors in terms of consumption. While electricity utilization in the industrial sector declined during the period from 1991 to 1993, in the same period the electricity

[1] Coal is used in three sectors of LMA, i.e. commercial, industrial, and residential sectors.

[2] Among the selected sectors for this study, only transport sector does not consume electricity due to low technology.

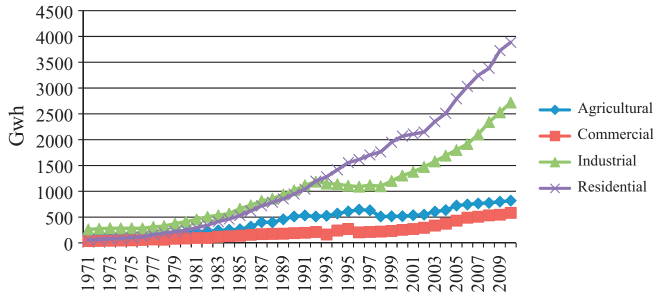

Fig. 4. Electricity consumption. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

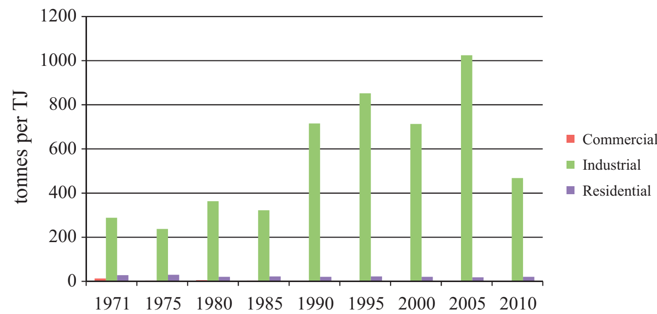

Fig. 5. CO_2 emissions from coal consumption. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

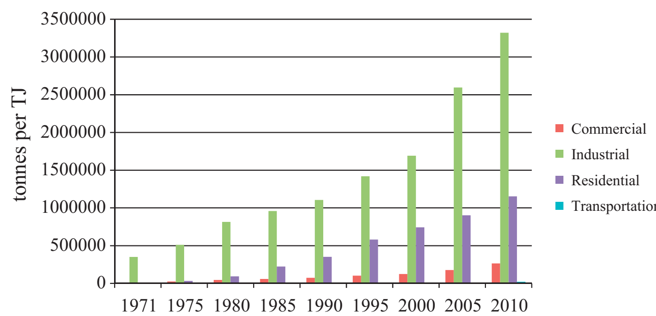

Fig. 6. CO_2 emissions from gas consumption. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

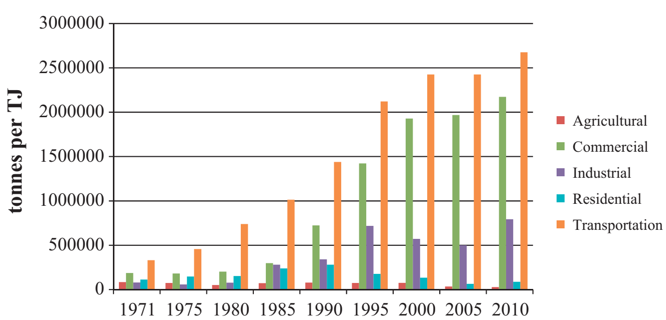

Fig. 7. CO_2 emissions from petroleum products consumption. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

consumption increased in the residential sector with escalating trend which has been continuous to date. A relative observation demonstrates that the electricity consumption of the residential sector has reached to 49% in 2010 from 13% in 1971, while that of the industrial sector increased to 34% in 2010 from 59% in 1971. Thus, all sectors are consuming electricity with increasing trend except that of agriculture which is increasing at a constant rate.

Resultantly, the industrial sector is the largest consumer of coal and gas energy sources from 1971 to 2010 where its consumption of coal, gas and petroleum products is 2–3 times higher than that of the other sectors of the city. The share of the industrial sector in coal consumption in 1971 was 87% of the total consumption and this share reached to almost 96% in 2010. Gas is largely consumed by the industrial and residential sectors because both sectors highly rely on this energy source to sustain their respective different activities. However, now transportation is also becoming a vigorous consumer of gas. In the same way, electricity is consumed by residential and industrial sectors which could also be due to the same reasons as above. Nevertheless, the reason for the present trend of consumption of petroleum products in the transportation sector might be due to lack of resources and technology, urbanization and/or increasing number of vehicles in the city. Nonetheless, urbanization, income level, population and lack of technology could be considered as the major causes.

3.2. Sectoral CO_2 emissions in LMA

As elucidated in Section 3.1, coal consumption has stopped in the commercial sector since 1989 while in the residential sector its share is almost 4% which is negligible compared to that of the industrial sector in 2010. Therefore, since coal is no longer used in these sectors, CO_2 emissions from coal consumption are also near zero out of total share in the commercial sector. The CO_2 emissions in the commercial, industrial and residential sectors were 13.11, 288.45 and 28.09 tonnes/TJ, respectively in 1971 (Fig. 5). In 2010, the CO_2 emissions from commercial, industrial and residential sectors were 0, 468.27 and 20.06 tonnes of CO_2 per TJ, respectively. While the CO_2 emission from the residential sector is diminishing with decreasing trend, it is expected to decrease further to almost nil in the coming years. Thus, the industrial and commercial sectors are the exclusive CO_2 emitters from the use of coal energy.

Gas is a profuse energy source utilized in the industrial sector of the city which is obvious in the energy consumption analysis. From 1971 to 2010, the industrial sector is the prevalent CO_2 emitter in the city (Fig. 6). CO_2 emission in the industrial sector increased by almost 10-folds from 1971 to date and is expected to increase at the same rate in the future as well. The rest of the sectors are not good competitors to the industrial sector as the current CO_2 emission from the latter remained the highest. The residential sector is the next sector to the industrial sector in terms of emission followed by the commercial and lastly by the transport sector. All these sectors have grown in size and thus are emitting more GHG compared to their emissions in the past while reliance on the use of gas in the city is increasing more and more than ever before.

All five major sectors consume petroleum products in one way or another resulting in abundant use of energy and so are their GHG emissions, but the most interesting results could be gleaned from the following category of emissions. From 1971 to 2010, two sectors such as the transportation and commercial sectors have been dominant in the CO_2 emissions (Fig. 7). The emissions of the commercial and transportation sectors were 187,511 and 331,905 tonnes of CO_2 per TJ in 2010. Three sectors using petroleum products are the main CO_2 emitters in the city, led by the transportation sector as the largest emitter all the time followed by the commercial and industrial sectors. Furthermore, the commercial, industrial and transportation sectors have increased their CO_2 emissions by 11-, 9- and 8-folds, respectively, from 1971 to 2010. Interestingly however, the agricultural and residential sectors have reduced their emissions from petroleum products consumption as is noticeable from Fig. 7. Both sectors have reduced their CO_2 emissions by 0.3 and 0.8 times, respectively, from 1971 to 2010. Currently, the share of

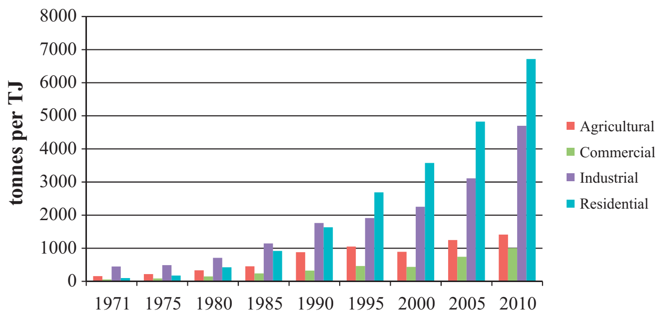

Fig. 8. CO_2 emissions from electricity consumption. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

agricultural and residential sectors in total CO_2 emissions is almost 0% and 2%, respectively.

Fig. 8 explains the CO_2 emissions from electricity consumed by four sectors of LMA from 1971 to 2010. The analysis shows that CO_2 emissions have been increased in each sector from the past to present, and the most vulnerable point is that emission is increasing with escalating trend. The CO_2 emissions from agricultural and commercial sectors increased by almost 9 and 17 times, respectively, in 2010 than 1971. Among all sectors, the residential sector has boosted its emission amazingly with an increase of 67-folds from 1971 to the present. Although the industrial sector has been leading since 1971 until 1990, since then the residential sector took the lead until now and thus is the largest CO_2 emitter from electricity consumption in the city. Hence, all sectors consuming electricity are emitting CO_2 with increasing trend and the respective increments have been continuous.

Therefore, coal energy source is the least and petroleum products are the largest emitters of CO_2 in the city, where such trend could be expected to reduce and increase more, respectively. Evidently, if all sectors are consuming more of these energy forms, thus resultantly, these sectors are also emitting GHG in the same way as well. So far, the industrial sector is the largest emitter of CO_2 utilizing gas and coal while the residential sector is the next largest emitter for its electricity use followed by commercial and transportation sectors. Large extent of emissions might happen in LMA because it is a commercial and industrial center. All sectors mainly rely on these energy sources especially for the gas and electricity based machinery used in industries. Moreover, these are also the less expensive and more available energy resources to all sectors in the city. Agriculture area is reducing its emission mainly due to less agricultural activities in the city or due to the decreasing agriculture area. However, transportation sector is emitting CO_2 at large scale due to the abundant use of the energy sources in vehicles, a situation which is quite vulnerable in the future if no substitute energy is made available.

3.3. Forecasts of the energy use in LMA

This section explains the results of the forecasts generated for the next 20 years through an ARIMA model as presented in Table 5. In the aspect of coal resource which has salient potentials to reduce energy use within the LMA, the data indicated that the commercial and residential sectors are almost the minor sectors in terms of coal energy utilization. The commercial sector in the city is no longer a consumer of coal since 1989 while the industrial sector will stop utilizing coal in about 2020 and completely stop in 2025 according to the forecast analysis. However, the residential sector will still use this energy until the period we forecast (2030) but its consumption will decrease with diminishing trend which appears continuous.

The forecast analysis (Table 5) also shows that the industrial and residential sectors in the city are again the large consumers of gas and their consumption will increase to almost 2.1- and 2.3-folds, respectively in 2030. The transportation sector will also add almost 1.6-folds to its gas consumption in 2030 even though it is the least gas consumer among the other sectors in the city but its trend to consume gas energy will remain increasing and consumption will increase by almost 1.6-folds in 2030. Therefore, the industrial sector will continue to lead in terms of gas consumption followed by the residential and commercial sectors in 2030.

Being the most renowned energy source for all major sectors in the LMA, petroleum products are leading among the selected energy sources. As indicated in Table 5, for all sectors of the economy petroleum products will be consumed until 2030. Energy consumption in agriculture sector will be zero by 2030 while consumption in the case of the commercial sector will increase by almost 1.3 times in 2030. There will be an increase of 1.4 times in the transportation sector and 1.6-folds increase in the industrial sector of the city. Thus until 2030, the share of utilization of petroleum products as source of energy by the transport and industrial sectors will be higher than those of the commercial and residential sectors.

In the electricity energy source category, the forecast analysis indicated that commercial and agricultural sectors are not major consumers compared to the residential and industrial sectors. While energy consumption will increase in the agricultural sector in 2030 by almost 1.4-folds, energy use in the commercial sector will increase by almost 1.4 times too. Likewise, energy

Table 5
Results of energy use forecasts generated through ARIMA model.

		2010	2011	2015	2020	2025	2030
Coal (thousand metric tonnes)	Commercial	0	0	0	0	0	0
	Industry	250	231.817	170.089	70.8464	0	0
	Residential	11	10.578	9.69061	8.89181	8.21658	7.57747
Electricity (GWh)	Agriculture	817.27	836.298	910.134	1003.08	1096.04	1188.99
	Commercial	580.9	596.024	651.131	721.21	791.289	861.367
	Industry	2718.78	2907.5	3748.66	4906.98	6183.91	7581.88
	Residential	3887.36	4146.33	5056.45	6244.85	7728.56	9149.65
Gas (mm cft)	Commercial	3990.89	4299.94	5556.76	7272.73	9155.95	11198.7
	Industry	57251.19	60843.2	71148.1	89481.1	105,691	124,967
	Residential	19884.59	20905.7	24567.1	29626.4	35167.8	41190.1
	Transport	6992	6862.28	7447.99	8867.71	9797.19	11409.3
Petroleum products (tonnes)	Agriculture	8615.5	9085.12	6687.39	4488.98	1931.2	0
	Commercial	664533.8	674,949	717,796	784,004	854,271	925,577
	Industry	242445.5	254,470	285,380	320,050	355,085	390,146
	Residential	27078.6	27,312	26606.8	25891.5	25176.1	24460.8
	Transport	818158.4	837,644	910,333	1,000,000	1,090,000	1,180,000

Table 6
Forecasts of CO_2 emission (in tonnes of CO_2 per TJ) generated through ARIMA model.

		2010	2011	2015	2020	2025	2030
Coal	Commercial	0	0	0	0	0	0
	Industry	731.2	643.847	510.211	468.27	0	0
	Residential	20.60388	19.8134	18.1513	16.6551	15.3903	14.1932
Electricity	Agriculture	1412.24256	1477.35	1609.32	1748.75	1965.97	2092.56
	Commercial	1003.7952	1038.32	1115.43	1173.55	1238.55	1302.79
	Industry	4698.05184	5010.06	6253.21	7867.81	9631.26	11560.3
	Residential	6717.35808	7164.86	8737.54	10791.1	13,355	15810.6
Gas	Commercial	264900.831	285,414	368,838	482,737	607,739	743,331
	Industry	3320671.5	3,530,000	4,130,000	5,190,000	6,130,000	7,250,000
	Residential	1153341.81	1,210,000	1,420,000	1,720,000	2,040,000	2,390,000
	Transport	21089.1306	21923.4	26941.1	34997.4	44294.3	54728.9
Petroleum products	Agriculture	28180.9559	25808.7	21418.4	14732.8	8340.24	0
	Commercial	2173663.48	2,210,000	2,350,000	2,560,000	2,790,000	3,030,000
	Industry	793029.533	832,362	933,466	1,050,000	1,160,000	1,280,000
	Residential	88573.0175	89336.4	87029.9	84690	82350.1	80010.3
	Transport	2676163.4	2,740,000	2,980,000	3,280,000	3,570,000	3,870,000

consumption in the industrial and residential sectors will rise by almost 2.7- and 2.3-folds, respectively from 2010 to 2030. The residential sector will remain the leading consumer in electricity in the city until the period we forecast and such trend will be increasing.

The results therefore showed that in the future, the industrial sector will follow a continuous increasing trend for its coal and gas consumption while the residential sector in the electricity energy consumption compared with the other sectors, whereas increase in petroleum products consumption will be slower. This could be due to economic growth, industrialization shift and/or less availability of other resources in the city. Likewise, transportation sector will increase its petroleum products consumption in contrast to agricultural sector which will decrease its consumption which could be due to almost the same factors as discussed in Section 3.1. Thus, in the overall, there will be continuous increasing trend in the industrial and residential sectors but decreasing trend in the agricultural sector in the future.

3.4. CO_2 emissions forecasts of LMA

There will be no CO_2 emissions by the commercial sector from coal consumption during the forecast period. Although there is moderate contribution of the industrial sector to gas emission, this is expected to be completely nil in 2020. Interestingly therefore, as shown in Table 6, emissions from residential sector will continue until 2027 while emissions from the commercial and industrial sectors will be zero by 2030.

Out of four sectors which consume gas in their respective diverse activities and emit CO_2 regularly with increasing trend, the industrial sector being the major consumer of energy, will remain the leading emitter until 2030 with an emission increment of 2.1-folds followed by the residential sector which will double its emissions by 2030 based on its level of emission in 2010. The commercial and transportation sectors will have common increment of almost 2.5 times higher in 2030 than that of now. Thus, all sectors are emitting CO_2 with an increasing trend whether this increase is higher or lower than the current amount of emissions but anyhow the trend seems to be increasing progressively.

A logical amount of CO_2 emissions can be found in the category of petroleum products as source of energy, as presented in Table 6. The commercial, industrial and transportation sectors are the significant contributors in this regard, where their emissions in 2010 are almost 1.5 times less than those forecast in 2030. With the transportation sector leading the way, it is followed by the industrial and commercial sectors in terms of CO_2 emissions through their utilization of this source of energy. Agricultural is the only sector that will contribute the least to the CO_2 emissions in view of its diminishing use of petroleum products. Since utilization of petroleum products in agricultural sector will be abolished completely by 2020 so is its CO_2 emissions by default. All other sectors will continue to emit CO_2 with an increasing trend until 2030 as per our analysis and may even continue to increase in the following years as well if further analysis is made.

In case of electricity, an increasing trend of CO_2 emissions is present in most of the sectors except in the agricultural sector. CO_2 emissions in agricultural sector will decrease by 1.5-folds but there is an upward push of 1.2, 2.4 and 2.4 times in CO_2 emissions by the commercial, industrial and residential sectors, respectively. Residential sector will be the largest CO_2 emitter in the electricity energy source category followed by the industrial and commercial sectors of the city with corresponding increasing trends (Table 6).

Among all energy sources whether direct (coal, gas and petroleum) or indirect (electricity), gas and petroleum products are the major sources of GHG emissions. Although the rest of the sources are also contributing to the level of GHG emissions of the city but their contribution is quite lower than those by the two energy sources. Correspondingly, the industrial sector of the city will be the major consumer of coal and gas while the residential sector in terms of electricity in the future. This could be due to the fact dependence on these energy sources by these sectors is high or possibly because of the elastic supply of these sources and/or perhaps due to the impact of technological

Table 7
Statistics on land cover/land use change of Lahore Metropolitan Area (hectares).

LC/LU classes changing to built-up areas	1975–1981	1981–1999	1999–2009
Bare areas to built-up areas	270	6397	25,288
Water to built-up areas	2	50	85
Dense vegetation/agriculture field to built-up areas	16	916	2511
Sparse vegetation/agriculture field to built-up areas	53	986	2656
Grasses to built-up areas	130	2482	879
Sparse trees to built-up areas	211	4187	1455

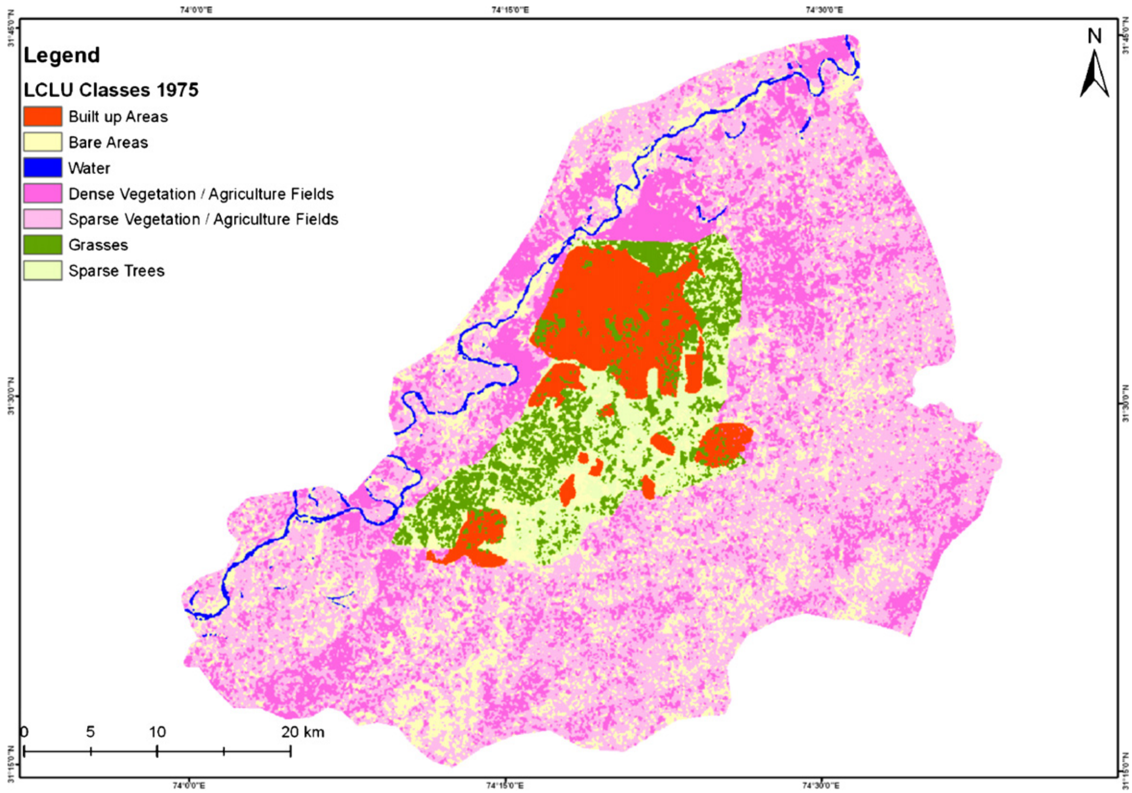

Fig. 9. Land cover/land use basic map of 1975. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

innovations. Hence, we can say that in the future, the industrial and residential sectors would be high emitters of CO_2 with agriculture as the least and the reasons could be the same as described in Section 3.3.

3.5. Land cover/land use (LC/LU) change assessment

The entire study area of 193,204 ha has the classes of LC/LU for 1975, 1981, 1999 and 2009 as summarized in Table 7. The scenes

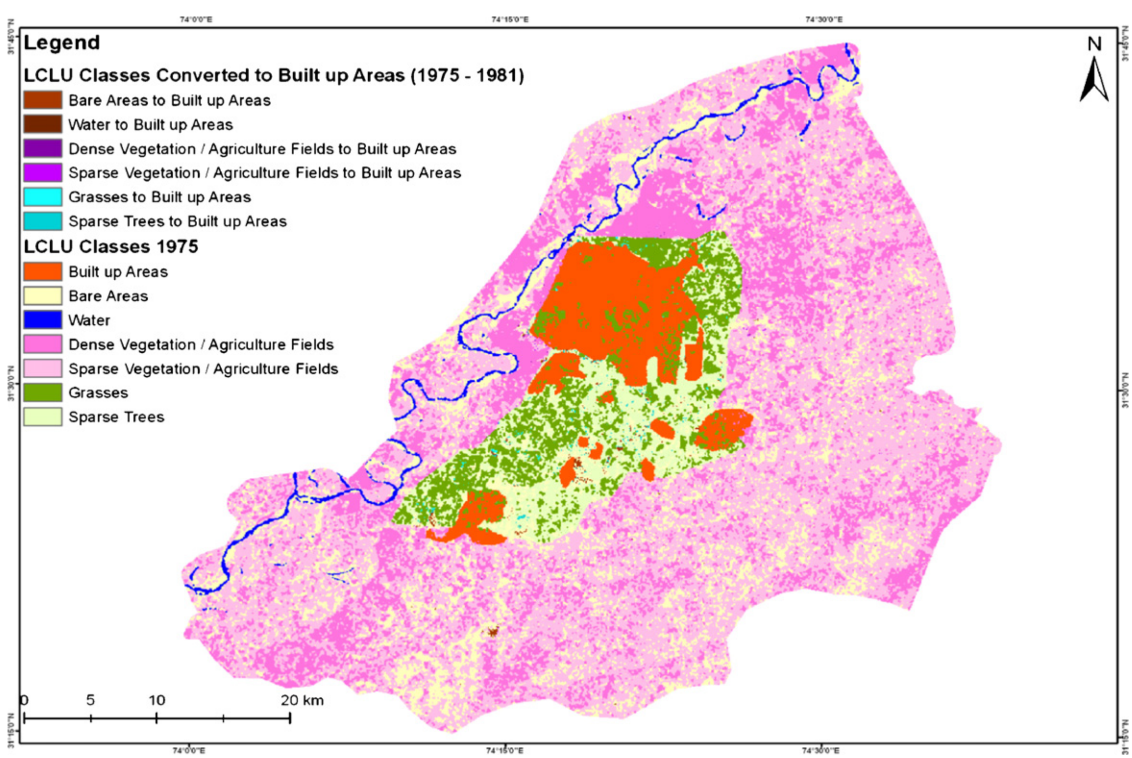

Fig. 10. Land cover/land use change map from 1975 to 1981. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

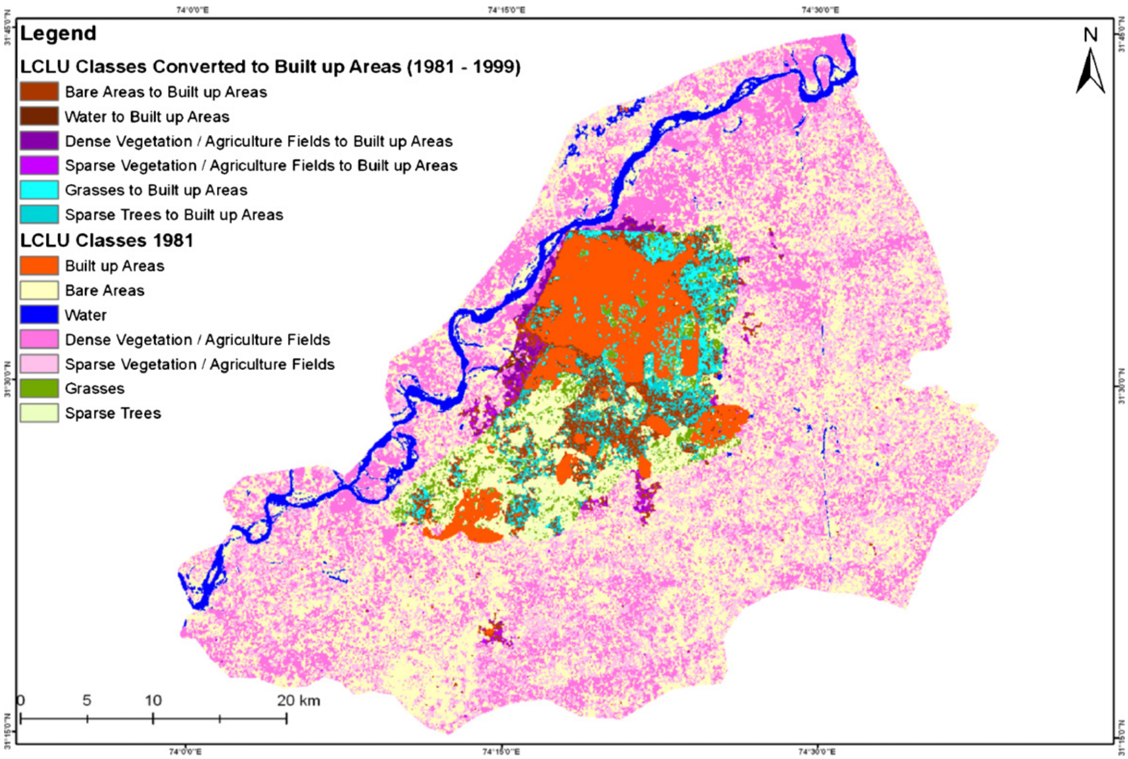

Fig. 11. Land cover/land use change map from 1981 to 1999. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

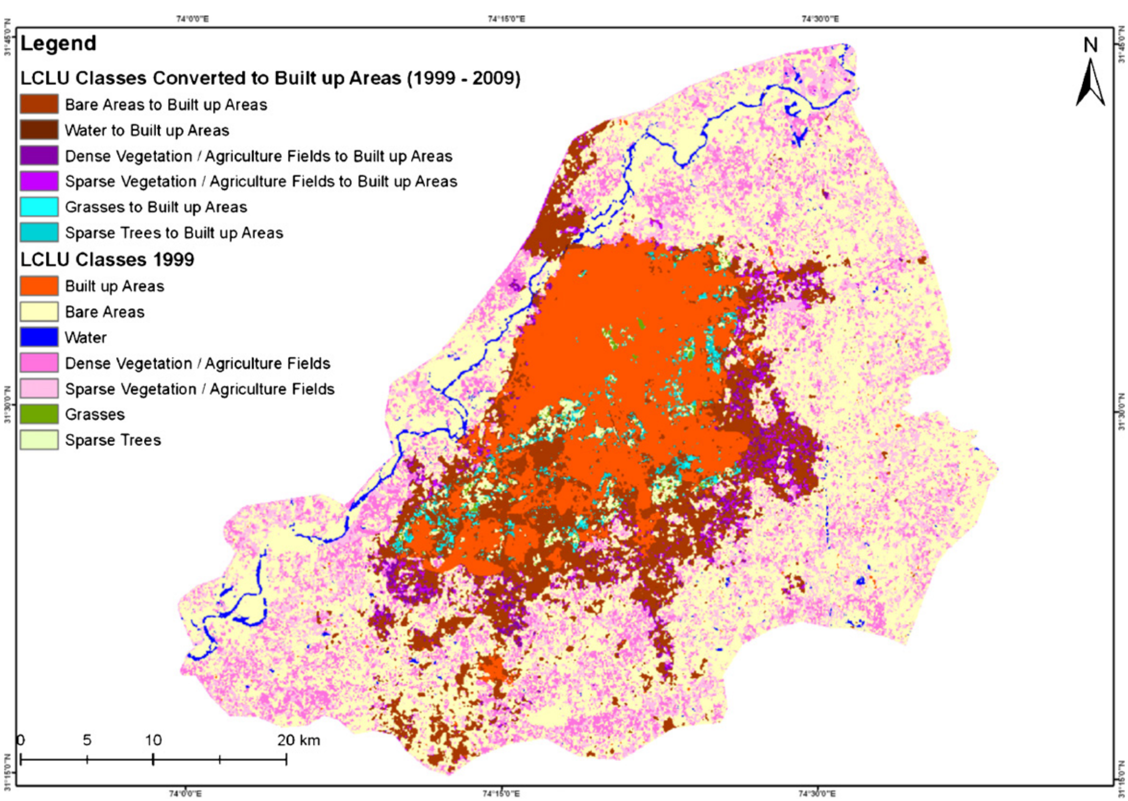

Fig. 12. Land cover/land use change map from 1999 to 2009. (For interpretation of the references to color in this artwork, the reader is referred to the web version of the article.)

in these four years have been utilized for land change and land use assessment, starting with the basic map of 1975 land use followed by the analysis of the change detected. In analyzing the land use area change for 1975–1980, we observed that there is an increase of 681 ha in the urban sprawl/built up area, a situation which is complemented by the official census [62] indicating a constant increase in population and urbanization of the study area. When we analyzed the change for 1981–1999, we observed an increase in the urban sprawl by 15,017 ha, which is again supported by the census data since there was a sharp increase in the population in the early 1980s which can be considered as the main contributing factor for the growth in urban sprawl. The same trend was observed when we analyzed the land use change from 1999 to 2009, where a huge increase of 32,873 ha was observed. From 1975 to 2009, a gradual decrease was observed in agriculture land, natural vegetation, barren land and water bodies, and especially the sparse trees which is a natural phenomenon when there is increase in urban sprawl.

Agriculture area declined to 36,916 ha from 1975 to 2009 while sparse trees decreased by 10,683 ha and so are the grassy area by 10,226 ha which is too much in such a metropolitan area. Agriculture is the only sector among all sectors of economy which retains its potential to reduce CO_2 emissions in the city but such reduction is because of two reasons, namely: (1) agriculture area is becoming less and less as urbanization is increasing and urban sprawl is growing, and (2) shift in energy use technology. In the past 20–30 years, farming machines were operated with intensive use of diesel oil, petrol, and high speed diesel (HSD) among others, but now electricity and gas base machinery have been introduced which lessen the use of petroleum products in the agriculture sector although such situation could be different in other mega cities of Pakistan. The result of the LC/LU change analysis also describes the change in urban and vegetation areas where barren land is the largest land area converted to built-up area followed by sparse trees in the metropolitan area, as well as agriculture and grass areas. Built-up area has drastically increased from 1975 to 2009 while vegetation has been reduced in the same way which is a clear proof of LC/LU change occurring in the city within the last 40 years. Urbanization has increased corresponding to the reduction of agriculture and vegetation areas with absolute stature and this is the reason why CO_2 emission and energy use in all sectors of the city has been increasing with escalating trends. In the LC/LU classification (Figs. 9–12), all classes have been reduced in their respective areas except in urban area/built-up area which changed by almost 32% from 1975 to 2009.

Consequently, there exists a positive relationship between energy use, CO_2 emissions and LC/LU in the LMA. The land use changed with the passage of time which makes the demand for intensive energy use and profuse CO_2 emissions in the city ultimately increasing, and this trend is expected to continue in the same fringe if such issue is not properly addressed.

4. Conclusion

This study had three objectives to accomplish and through the analyses we achieved the objectives one by one. Results of the analyses illustrate that energy use has been increasing from the past to the present and is expected to increase at relatively the same trend in the future as well. In terms of commercial energy sources, there is a radical shift in the pattern of utilization by the industrial, residential, commercial, and transportation sectors of the city and among these, the industrial and residential sectors are more vulnerable to increase their utilization and therefore need immediate attention to be organized, while the agriculture sector has reduced its energy use since 1971 up to the present. Currently, the share of the commercial, industrial, residential, and transportation sectors at 23%, 39%, 12% and 26%, respectively in terms of CO_2 emissions in 2010, is expected to continue at more or less same rate of increment as that of the present. Based on the CO_2 emissions analysis, the commercial and residential sectors have shown severe changes in their emissions from the past to the present, and the same trend is expected to continue until 2030 and beyond if further forecast would be conducted. Meanwhile, the commercial and residential sectors have increased their gas consumption by 22- and 96-folds, respectively from 1971 to 2010 whereas 17% and 67% electricity consumption respectively.

The total CO_2 emissions by all sectors from electricity consumption in the city have been increased from 764.27 to 13831.44 tonnes of CO_2 per TJ from 1971 to 2010. This is quite a serious situation as well because these sectors which continue to grow would also continue to emit CO_2 at the same rate so that by 2030, this emission rate could reach up to 30766.25 tonnes of CO_2 per TJ, respectively. As a matter of fact, the trend of CO_2 emissions from all sectors of economy in the city is increasing and will continue to increase until the period we forecast (2030) using the ARIMA model except the agriculture sector which showed a decreasing trend. This means the agricultural sector is expected to show more changes in the future. From 1971 to 2010, the transportation sector has been the largest emitter of CO_2 from its consumption of petroleum products. Its level of CO_2 emissions from 1971 to 2010 has increased from 797771.77 to 5759610.38 tonnes of CO_2 per TJ, respectively which is pushing forward by almost 8-folds.

Moreover, the land cover/land use (LC/LU) change analysis demonstrates that among all five classes, the urban area/built-up area has grown rapidly from 1975 to 2009 with a total change of 32% while sparse trees, agriculture and grasses areas have shrunk from 6% to 0%, 21% to 7% and 5% to 0%, respectively. This also supports our logical statement that CO_2 sources have been increased in the city whereas CO_2 sinks have decreased from the past to the present which could be caused by more energy use and CO_2 emission as well as other related GHG emissions within the LMA.

Furthermore, this study although still preliminary and baseline, describes the sectoral break down of energy use and CO_2 emissions and their forecasts, and thus, could serve as baseline study and pave the way for further studies. There is however, an additional need to conduct studies that would include all energy sources of the city including the non-commercial sources as well to find out the factors affecting the CO_2 emissions and energy use of the city through different approaches. Mitigation of CO_2 emissions with the least cost strategies to provide the best policy implications to local policy makers would be necessary to impede the current increasing trend of energy use and CO_2 emissions in the city. Last but not least, there is also a need to provide such baseline information of other mega and metropolitan cities of Pakistan in order that with such database and baseline studies, a comprehensive climate action plan could be designed by the government and policy makers aiming to cope with future disasters at local levels as well as serving as preparation platform against threats from climate change.

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References

[1] Sattherwaite D. Cities' contribution to global warming: notes on the allocation of greenhouse gas emission. Environment and Urbanization 2008;20(2):539–49.
[2] Wende W, Huelsmann W, Marty M, Bressel GP, Bobylev N. Climate protection and compact urban structures in spatial planning and local construction plans in Germany. Land Use Policy 2010;27:864–8.
[3] Tubiello FN, Fischer G. Reducing climate change impacts on agriculture: global and regional effects on mitigation, 2008–2080. Technological Forecasting and Social Change 2007;74:1030–56.
[4] World Development Indicator. World development indicator 2011. The World Bank; 2011.
[5] SDPI. Quarterly Pakistan forest digest, vol. 1(1). Sustainable Development Policy Institute; 2010. p. 15–6.
[6] Asif M. Sustainable energy options for Pakistan. Renewable and Sustainable Energy Reviews 2009;13:903–9.
[7] HDIP. Pakistan Energy Yearbook 2008, Hydrocarbon Development Institute of Pakistan. Ministry of Petroleum and Natural Resources. Government of Pakistan, Islamabad; 2009.
[8] Ahmad DI, Mulk SU. Final report of task force on climate change. Islamabad: Government of Pakistan, Planning Commission; 2010.
[9] IEA. Key world statistics. Paris: International Energy Agency; 2009.
[10] Alam S, Fatima A, Butt MS. Sustainable development in Pakistan in the context of energy consumption demand and environmental degradation. Journal of Asian Economics 2007;18:825–37.
[11] Chen X, Liu S, Zhu Z, Vogelmann J, Li Z, Ohlen D. Estimating aboveground forest biomass carbon and fire consumption in the U.S. Utah high plateaus using data from forest inventory and analysis program, landsat and landfire. Ecological Indicator 2009, doi:10.1016/j.ecolind.2009.03.013.
[12] Demirel H, Sertel E, Kaya S, Seker DZ. Exploring impacts of road transportation on environment: a spatial approach. Desalination 2008;226:279–88.
[13] Phdungslip A. Integrated energy and carbon modeling with a decision support system: policy scenarios for low-carbon city development in Bangkok. Energy Policy 2009, doi:10.1016/j.enpol.2009.10.026.
[14] Song HJ, Lee S, Maken S, Ahn SW, Park JW, Min B, Koh W, et al. Environmental and economic assessment of the chemical absorption in Korea using the LEAP model. Energy Policy 2007;35:5109–16.
[15] Brown MA, Southworht F, Sarzynski A. The geography of metropolitan carbon footprints. Policy and Society 2009;27:285–304.
[16] Gillenwater M. Forgotten carbon: indirect CO_2 in Greenhouse gas emission inventories. Environmental Science and Policy 2008;11:195–203.
[17] Kennedy C, Steinberger J, Gasson B, Hansen Y, Hillman T, Miroslav H, Pataki D, et al. Methodology for inventorying greenhouse gas emissions from global cities. Energy Policy 2010;38:4828–37.
[18] Parshall L, Gurney K, Hammer SA, Mendoza D, Zhou Y, Geethakumar S. Modeling energy consumption and CO_2 emissions at the urban scale: methodological challenges and insights from the United States. Energy Policy 2010;38:4765–82.
[19] Schulz NB. Delving into the carbon footprints of Singapore-comparing direct and indirect greenhouse gases emissions of a small and open economic system. Energy Policy 2010;38:4848–55.
[20] Scotti M, Bondavalli C, Bodini A. Ecological footprint as a tool for local sustainability: the municipality of Pia-cenza (Italy) as a case study. Environmental Impact Assessment Review 2009;29:39–50.
[21] Sovacool BK, Brown MA. Twelve metropolitan carbon footprints; a preliminary comparative global assessment. Energy Policy 2009, doi:10.1016/j.enpol.2009.10.001.
[22] Ekholm T, Soimakallio S, Moltmann S, Höhne N, Syri S, Savolainen I. Effort sharing in ambitious, global climate change mitigation scenarios. Energy Policy 2010;38:1797–810.
[23] Gomi K, Shimada K, Matsuoka Y. A low-carbon scenario creation method for a local scale economy and its application in Kyoto city. Energy Policy 2010;38:4783–96.
[24] Pao HT. Forecasting energy consumption in Taiwan using hybrid nonlinear models. Energy 2009;34:1438–46.
[25] Povellato A, Bosello F, Giuponni C. Cost-effectiveness of greenhouse gas mitigation measures in the European agro forestry sector – a literature survey. Environmental Science and Policy 2007;10:474–90.
[26] Saikku L, Soimakalliu S. Top–down approaches for sharing greenhouse gas emission reductions; uncertainties and sensitivities in the 27 European union member states. Environmental Science and Policy 2008;11:723–34.
[27] Andersen O, Gossling S, Simonsen M, Walnum HJ, Peeters P, Neiberger C. CO_2 emissions from the transport of china's exported goods. Energy Policy 2010, doi:10.1016/j.enpol.2010.05.030.
[28] Avignon AD, Carloni FA, Rovere ELL, Dubeux CBS. Emission inventory: an urban public policy instrument and benchmark. Energy Policy 2010;38:4838–47.
[29] Cai W, Wang C, Chen J, Wang K, Zhang Y, Lu X. Comparison of CO_2 emission scenarios and mitigation opportunities in china's five sectors in 2020. Energy Policy 2008;36:1181–94.
[30] Chen GQ, Zhang B. Greenhouse gas emission in China 2007: inventory and input–output analysis. Energy Policy 2010;38:6180–93.
[31] Dhakal S. Urban energy use and carbon emissions from cities in china and policy implications. Energy Policy 2009;37:4208–19.
[32] Quadrelli R, Peterson S. The energy-climate challenge: recent trends in CO_2 emissions from fuel combustion. Energy Policy 2007;35:5938–52.
[33] Shrestha RM, Rajbhandari S. Energy and environmental implications of carbon reduction targets: case of Kathmandu valley, Nepal. Energy Policy 2010;38:4818–27.
[34] Yang C, McCollum D, McCarthy R, Leighty W. Meeting an 80% reduction in greenhouse gas emissions from transportation by 2050: a case study in California. Transportation Research Part D: Transport and Environment 2009;14:147–56.
[35] Zhang C, Shukla PR, Victor DG, Heller TC, Biswas D, Nag T. Baselines for carbon emissions in the Indian and Chinese power sectors: implications for international carbon trading. Energy Policy 2006;34:1900–17.
[36] Zhang B, Chen GQ. Methane emission by Chinese economy. Inventory and embodiment analysis. Energy Policy 2010;38:4304–16.
[37] Limmeechokchai B, Suksuntornsiri P. Assessment of cleaner electricity generation technologies for net CO_2 mitigation in Thailand. Renewable and Sustainable Energy Reviews 2007;11:315–30.
[38] Katuwal H, Bohara AK. Biogas-A promising renewable technology and its impacts on rural household in Nepal. Renewable and Sustainable Energy Reviews 2009;13:2668–74.
[39] Amjid SS, Bilal MQ, Nazir MS, Hussain A. Biogas, renewable energy resource for Pakistan. Renewable and Sustainable Energy Reviews 2011;15:2833–7.
[40] Sahir MA, Qureshi AH. Assessment of new and renewable energy resources potential and identification barriers to their significant utilization in Pakistan. Renewable and Sustainable Energy Reviews 2008;12:290–8.
[41] Sahir MA, Qureshi AH. Specific concerns of Pakistan in the context of energy security and geopolitics of the region. Energy Policy 2007;35:2031–7.
[42] Sheikh MA. Energy and renewable energy scenario of Pakistan. Sustainable Renewable and Sustainable Energy Review 2010;14:354–63.
[43] Sajjad SH, Blond N, Clappler A, Raza A, Shirazi SA, Shakrullah K. The preliminary study of urbanization, fossil fuels consumptions and CO_2 emission in Karachi. African Journal of Biotechnology 2010;9(13):1941–8.
[44] Shabbir R, Ahmad SS. Monitoring urban transport air pollution and energy demand in Rawalpindi and Islamabad using leap model. Energy 2010;35:2323–32.
[45] Qureshi IA, Huau L. Urban transport and sustainable transport strategies: a case study of Karachi, Pakistan. Tsinghua Science and Technology 2007;12(3):309–17.
[46] Asif M, Muneer T, Maubleu S. Prospects of solar water heating for textile industry in Pakistan. Renewable and Sustainable Energy Reviews 2006;10:1–23.
[47] Mirza UK, Ahmad N, Majeed T, Harijan K. Hydropower use in Pakistan: past, present and future. Renewable and Sustainable Energy Reviews 2008;12:164–51.
[48] Mirza UK, Ahmad N, Majeed T. An overview of biomass energy utilization in Pakistan. Renewable and Sustainable Energy Reviews 2008;12:1988–96.
[49] Liu Q, Shi M, Jiung K. New power generation technology options under greenhouse gas mitigation scenario in China. Energy Policy 2009;37:2440–9.
[50] IRIN. Humanitarian news and analysis. United Nations Development Program, available on http://www.irinnews.org/Report.aspx?ReportId=85179 [assessed 23.07.2011].
[51] PDS. Punjab development statistics. Lahore 54000, Pakistan: Bureau of Statistics, Government of Punjab; 2010.
[52] Ediger VS, Akar S, Ugurlu B. Forecasting production of fossil fuel sources in Turkey using a comparative regression and ARIMA model. Energy Policy 2006;34:3836–46.
[53] Kamal L, Jafri YZ. Time series models to stimulate and forecast hourly averaged wind speed in Quetta, Pakistan. Solar Energy 1997;61(1):23–32.
[54] Zhang GP. Time series forecasting using a hybrid ARIMA and neutral network model. Neurocomputing 2001;50:159–75.
[55] Ho SL, Xie M. The use of ARIMA Models for reliability forecasting and analysis. Computers Industrial Engineering 1998;35(1–2):213–6.
[56] Ho SL, Xie M, Goh TN. A comparative study of neural network and box-jenkins ARIMA modeling in time series predictions. Computer and Industrial Engineering 2002;42:371–5.
[57] Box GEP, Jenkins GM. Time series analysis: forecasting and control. 2nd ed. San Francisco: Holden Day; 1976.
[58] Brown BG, Katz RW, Murphy AA. Time series models to stimulate and forecast wind speed and wind power. Journal of Applied Meteorology 1984;23:1184–95.
[59] Gujarati DN, Potter D. Basic econometrics front matter preface. 4th ed. McGraw-Hill Companies; 2004.
[60] IPCC. IPCC guidelines for national greenhouse gas inventories. Prepared by the National Greenhouse Gas Inventories Program. Japan: IGES; 2006.
[61] Singh A. Review article digital change detection techniques using remotely-sensed data. International Journal of Remote Sensing 1989;10(6):989–1003.
[62] Economic Survey of Pakistan. Population, labor force and employment sector. Islamabad: Government of Pakistan; 2010.